Problem 3 (5 points)

In this problem you will use sklearn's support vector classification to study the effect of changing the parameter C, which represents inverse regularization strength.

Run the following cell to import libraries, define functions, and load data:

In [9]:
```
import numpy as np
import matplotlib.pyplot as plt
from sklearn.svm import SVC
from matplotlib.colors import ListedColormap

# Plotting functions:
def plot_data(X,c,s=30):
    lims = [0,1]

    markers = [dict(marker="o", color="royalblue"), dict(marker="s", color="crimson"),

    x,y = X[:,0], X[:,1]
    iter = 0
    for i in np.unique(c):
        marker = markers[iter]
        iter += 1
        plt.scatter(x[c==i], y[c==i], s=s, **(marker), edgecolor="black", linewidths=0

def plot_SVs(svm, s=120):
    sv = svm.support_vectors_
    x, y = sv[:,0], sv[:,1]
    plt.scatter(x, y, s=s, edgecolor="black", facecolor="none", linewidths=1.5)

def plot_SV_decision_boundary(svm, margin=True,extend=True, shade_margins=False, shade
    ax = plt.gca()
    xlim = ax.get_xlim()
    ylim = ax.get_ylim()

    xrange = xlim[1] - xlim[0]
    yrange = ylim[1] - ylim[0]

    x = np.linspace(xlim[0] - extend*xrange, xlim[1] + extend*xrange, 200)
    y = np.linspace(ylim[0] - extend*yrange, ylim[1] + extend*yrange, 200)

    X,Y = np.meshgrid(x,y)
    xy = np.vstack([X.ravel(), Y.ravel()]).T
    P = svm.decision_function(xy)

    P = P.reshape(X.shape)
    ax.contour(X, Y, P, colors='k',levels=[0],linestyles=['-'])
    if margin:
        ax.contour(X, Y, P, colors='k',levels=[-1, 1], alpha=0.6,linestyles=['--'])

    if shade_margins:
        cmap = ListedColormap(["white","lightgreen"])
        plt.pcolormesh(X,Y,np.abs(P)<1,shading="nearest",cmap=cmap,zorder=-999999)

    if shade_decision:
```

```
        cmap = ListedColormap(["lightblue","lightcoral"])
        pred = (svm.predict(xy).reshape(X.shape) == 1).astype(int)
        plt.pcolormesh(X,Y,pred,shading="nearest",cmap=cmap,zorder=-1000)

    plt.xlim(xlim)
    plt.ylim(ylim)

def make_plot(title,svm_model,Xdata,ydata):
    plt.figure(figsize=(5,5))
    plot_data(Xdata,ydata)
    plot_SVs(svm_model)
    plot_SV_decision_boundary(svm_model,margin=True,shade_decision=True)
    plt.legend()
    plt.xlabel("$x_1$")
    plt.ylabel("$x_2$")
    plt.title(title)
    plt.show()

# Dataset 1:
x1 = np.array([0.48949729, 0.93403431, 0.77318605, 0.99708798, 0.7453347 ,       0.627
       0.74459769, 0.75305792, 0.79103743, 0.63603483, 0.7035605 ,       0.84037653, 0
       0.69268775, 0.74637666, 0.62823845, 0.92394124, 0.52824645,       0.66571952, 0
       0.68742653, 0.79431218, 0.76105703, 0.729959  , 0.58809188,       0.63920244, 0
       0.71621743, 0.68913748, 0.94206083, 0.83811487, 0.52095808,       0.72136467, 0
       0.660455  , 0.54130881, 0.99176949, 0.41660508, 0.61517452,       0.76214   , 0
       0.26571114, 0.51712792, 0.17642698, 0.38630807, 0.27326383,       0.4757757 , 0
       0.41828429, 0.55323218, 0.30897445, 0.51987077, 0.25015929,       0.29285768, 0
       0.43747171, 0.41560485, 0.40850384, 0.53710681, 0.2458796 ,       0.36389757, 0
       0.53785843, 0.56305326, 0.18442455, 0.4783044 , 0.341153  ,       0.59226031, 0
       0.54259663, 0.36260852, 0.28089588, 0.28126787, 0.5046967 ,       0.32032048, 0
       0.37573027, 0.43281125, 0.10385945, 0.45855828, 0.12496919,       0.43889099, 0
x2 = np.array([0.82692832, 0.64782992, 0.51168806, 0.66255369, 0.80959079,       0.748
       0.74030383, 0.76234673, 0.57673835, 0.76739864, 0.70551825,       0.76417749, 0
       0.72477217, 0.81890284, 0.75486623, 0.57160741, 0.71961768,       0.69643131, 0
       0.6174821 , 0.69385581, 0.72352607, 0.57192729, 0.69906178,       0.85159439, 0
       0.81828425, 0.61449583, 0.54882155, 0.61557563, 0.76571808,       0.63905784, 0
       0.79516325, 0.71840235, 0.67254172, 0.58651416, 0.5778736 ,       0.8128274 , 0
       0.3216439 , 0.43068008, 0.48166151, 0.29743746, 0.45100559,       0.37373449, 0
       0.3776663 , 0.39820282, 0.43011064, 0.32873478, 0.35169937,       0.25739568, 0
       0.26646292, 0.44178363, 0.28835415, 0.45468991, 0.19393014,       0.42472115, 0
       0.38262922, 0.36293124, 0.4006077 , 0.34750469, 0.35023348,       0.3905313 , 0
       0.40579986, 0.23702401, 0.38844385, 0.29752652, 0.18619147,       0.46662002, 0
       0.32186971, 0.37281822, 0.36488808, 0.37194919, 0.30829606,       0.39365028, 0
y1 = np.array([-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
       -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,       -1, -
        1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,        1,
        1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,        1])
X1 = np.vstack([x1,x2]).T

# Dataset 2:
z1 = np.array([0.4623709 , 0.68787981, 0.22665386, 0.42140211, 0.30510439,       0.534
       0.58131992, 0.21989461, 0.41031163, 0.2825145 , 0.71079507,       0.4301869 , 0
       0.25007082, 0.40050165, 0.45727726, 0.45009186, 0.3127013 ,       0.24118917, 0
       0.62142011, 0.24273132, 0.63236235, 0.39114511, 0.48803606,       0.51600837, 0
       0.779535  , 0.94994687, 0.73010308, 0.61598114, 0.61310177,       0.51381933, 0
       0.51162408, 0.62770167, 0.80566504, 0.53683386, 0.48664659,       0.66135962, 0
       0.82291395, 0.6414185 , 0.54730993, 0.67858451, 0.53265047,       0.49505561, 0
       0.64641634, 0.41411608, 0.64992294, 0.60316402, 0.88008764,       0.75418984, 0
z2 = np.array([0.83290004, 0.66234451, 0.65801115, 0.84029466, 0.70126933,       0.821
       0.81111503, 0.69181695, 0.81230644, 0.68982279, 0.70037483,       0.79716711, 0
```

```
       0.87396874, 0.63583241, 0.62337179, 0.71575062, 0.59439517,       0.59527384, 0
       0.81318113, 0.74471739, 0.76689873, 0.74142189, 0.58628648,       0.58050036, 0
       0.49047076, 0.61580307, 0.46660621, 0.41485462, 0.50601875,       0.55752863, 0
       0.37757746, 0.47083258, 0.59490871, 0.4743862 , 0.41337164,       0.30688374, 0
       0.41406711, 0.58475545, 0.43525632, 0.61888062, 0.47842385,       0.40661197, 0
       0.64427582, 0.37797242, 0.59767007, 0.2815758 , 0.5679225 ,       0.35863786, 0
y2 = np.array([-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
       -1, -1, -1, -1, -1, -1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,        1,
        1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1])
X2 = np.vstack([z1,z2]).T
```

Linearly Separable Dataset

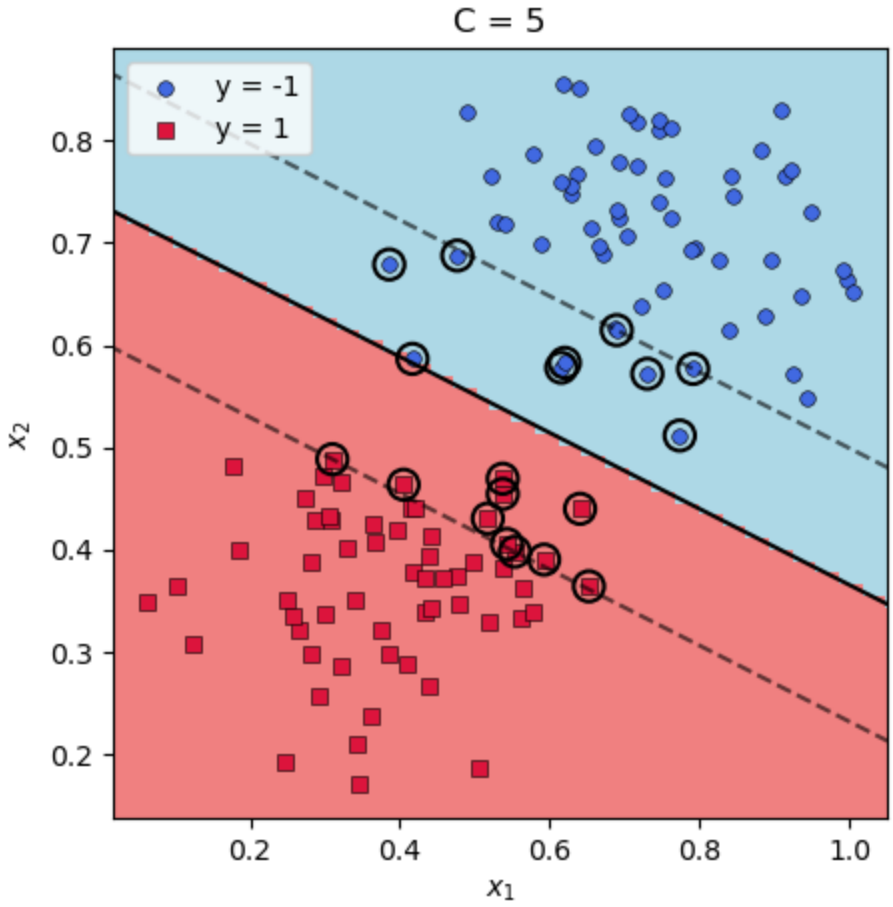
`X1` and `y1` are the features and classes for a linearly separable dataset. Train 4 SVC models on the data. Set `kernel="linear"`, but use four different regularization values:

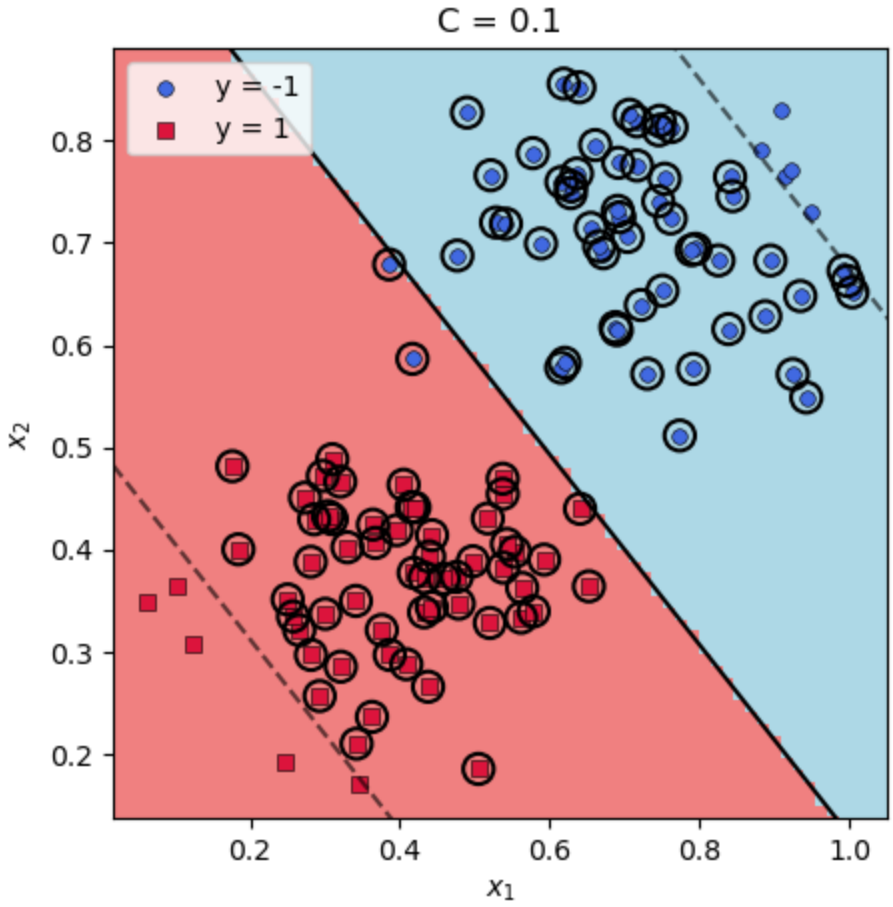
- C = 0.1
- C = 1
- C = 10
- C = 1000

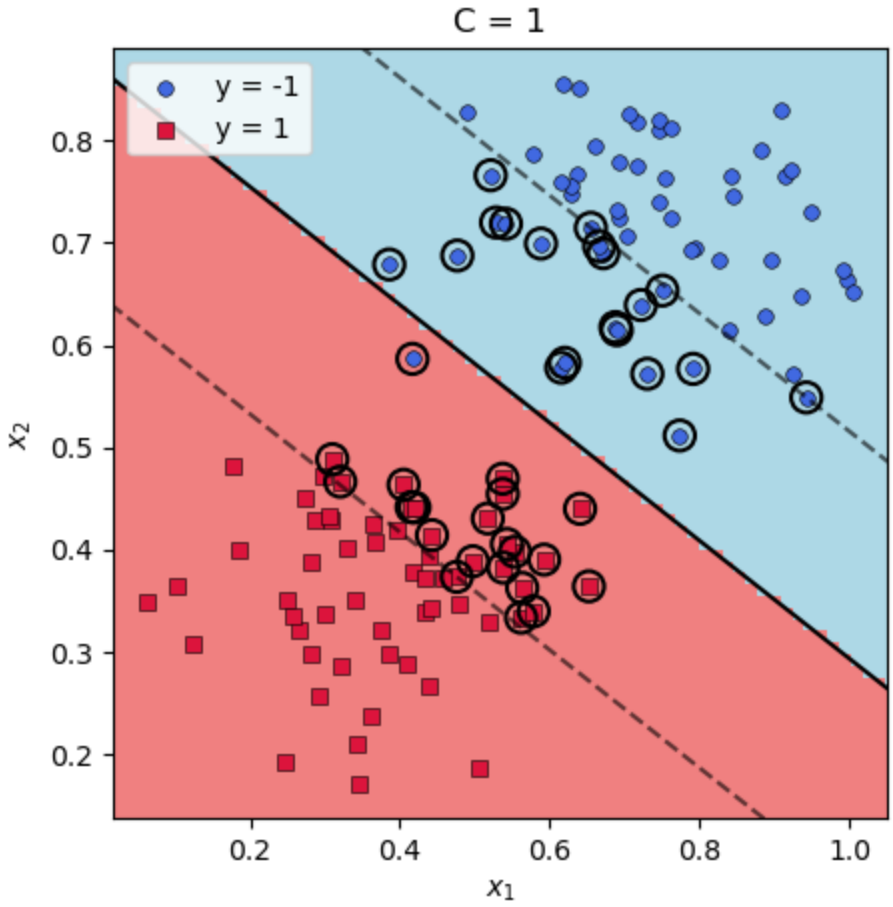
For each of these models, create a plot that shows the data, decision boundary, and support vectors, complete with a title that states the C value.
Use the provided function `make_plot(title,svm_model,Xdata,ydata)`

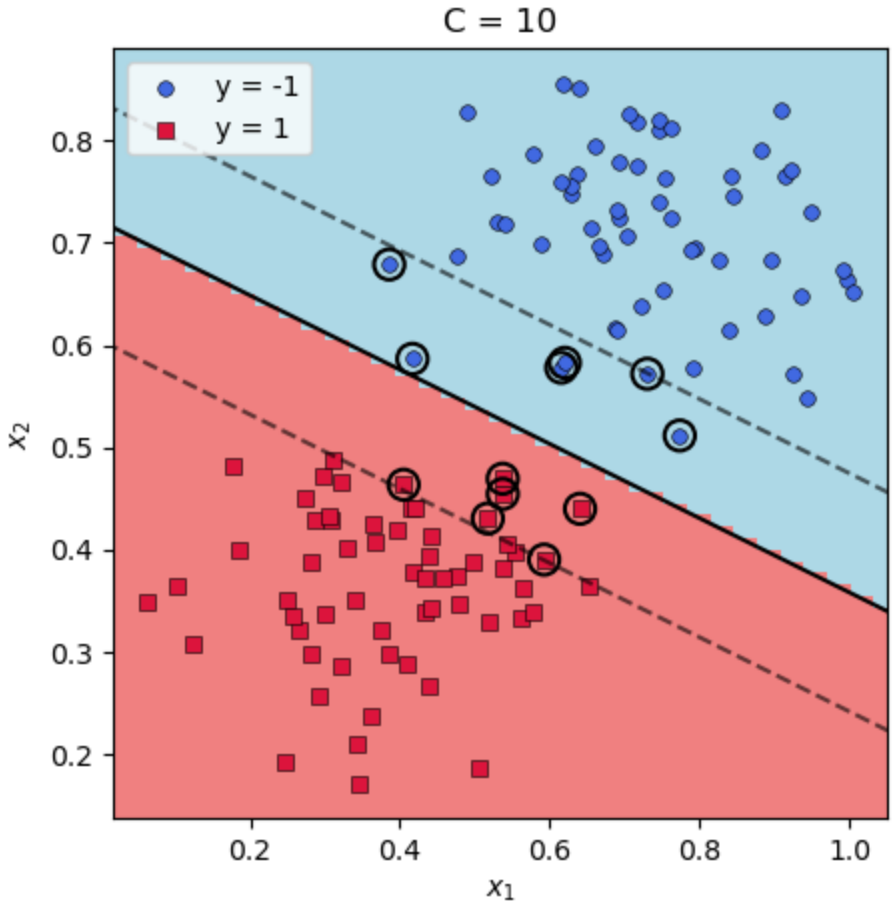
One example has been provided. Please repeat for all of the requested C values:

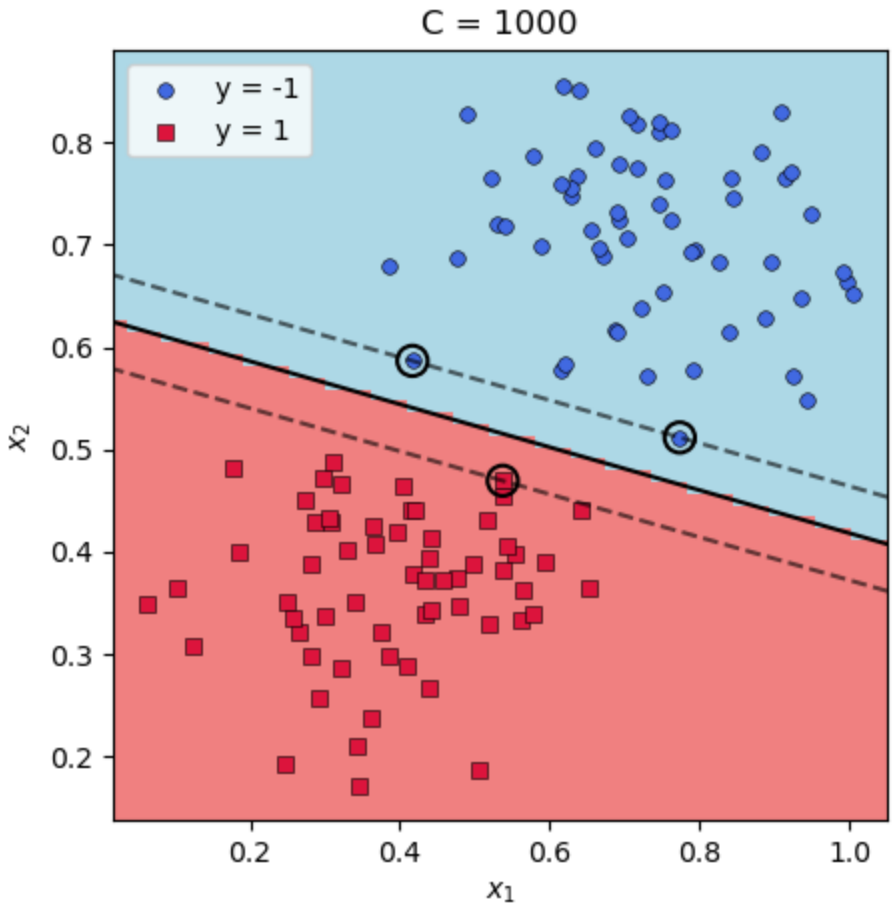
In [10]:
```
C = 5
svm = SVC(C=C,kernel="linear")
svm.fit(X1,y1)
make_plot(f"C = {C}",svm,X1,y1)

for C in [0.1,1,10,1000]:
    # YOUR CODE GOES HERE

    model = SVC(C=C,kernel = "linear")
    model.fit(X1,y1)
    make_plot(f"C = {C}",model,X1,y1)
```


C = 5
y = -1
y = 1
0.8
0.7
0.6
0.5
0.4
0.3
0.2
x_2
0.2
0.4
0.6
0.8
1.0
x_1


C = 0.1
y = -1
y = 1
0.8
0.7
0.6
0.5
0.4
0.3
0.2
x_2
0.2
0.4
0.6
0.8
1.0
x_1


C = 1
y = -1
y = 1
0.8
0.7
0.6
0.5
0.4
0.3
0.2
x_2
0.2
0.4
0.6
0.8
1.0
x_1

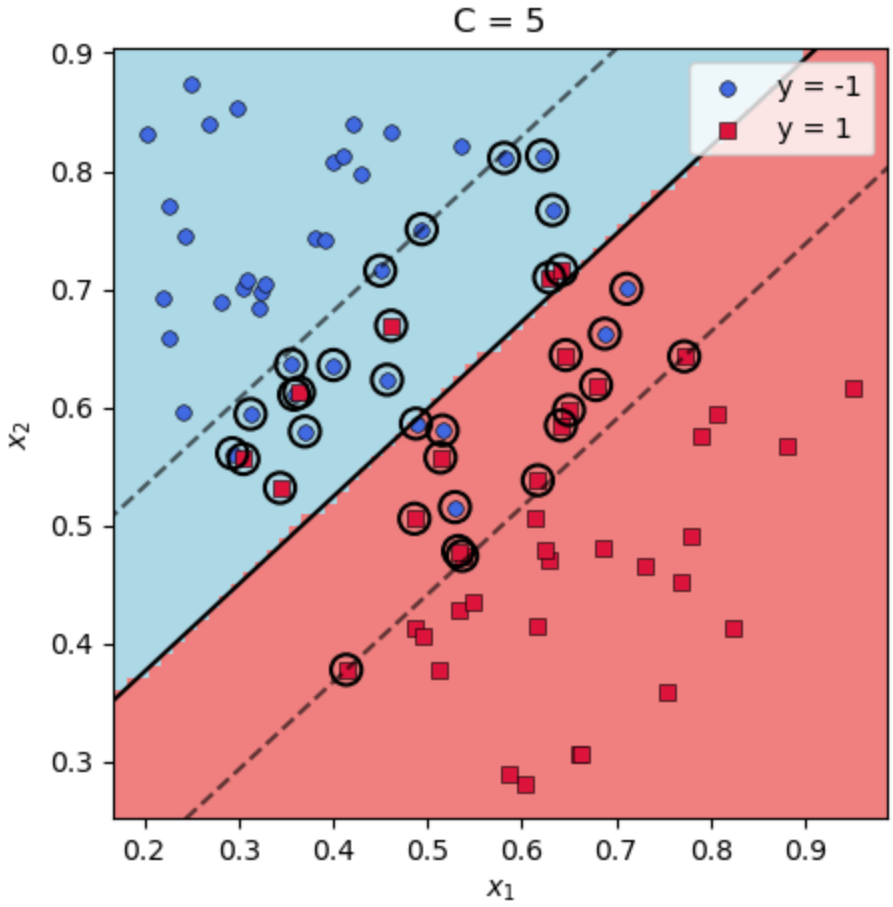

C = 10
y = -1
y = 1
0.8
0.7
0.6
0.5
0.4
0.3
0.2
x_2
0.2
0.4
0.6
0.8
1.0
x_1

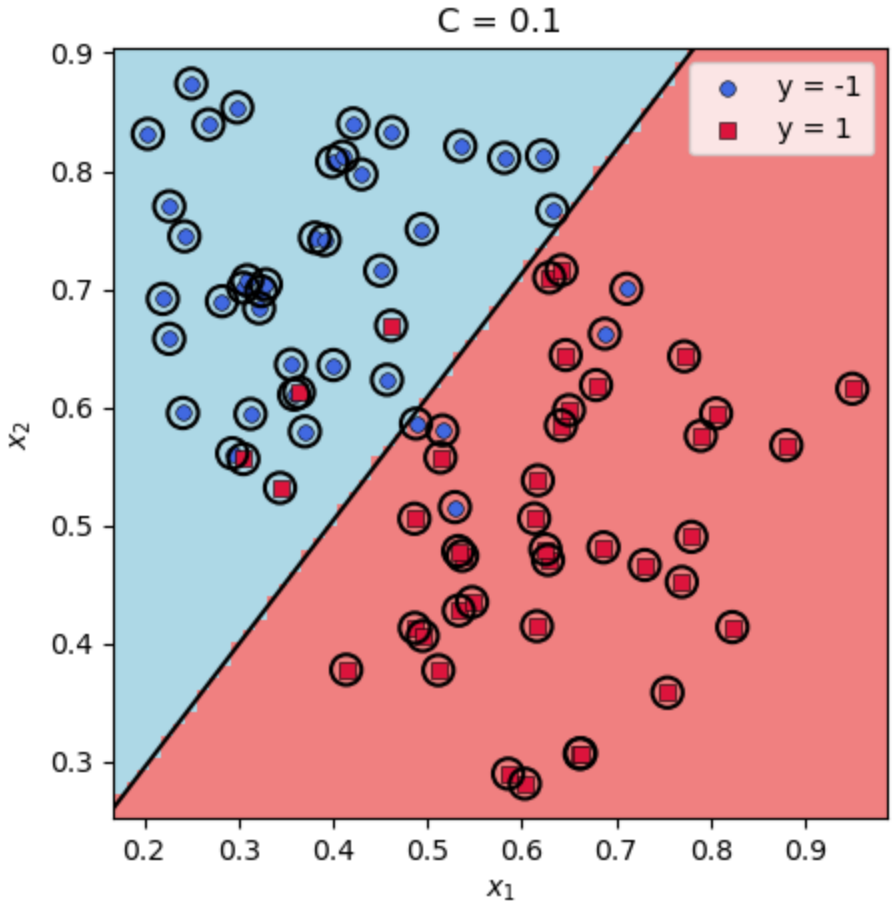


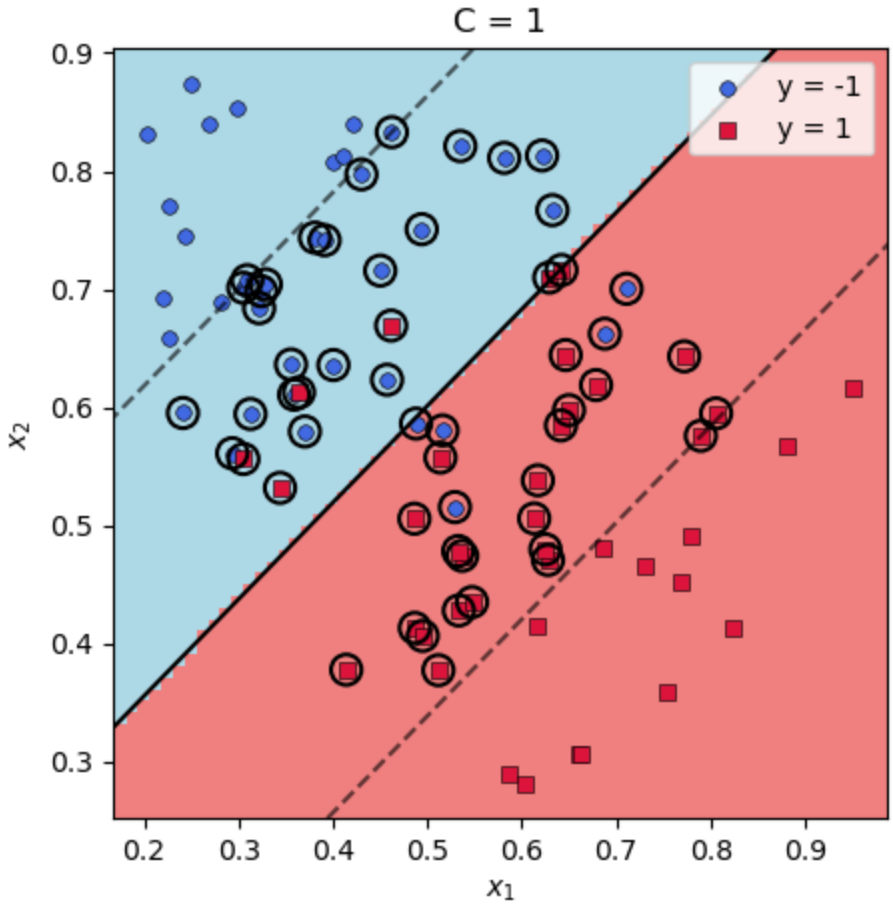
Linearly Non-Separable Dataset

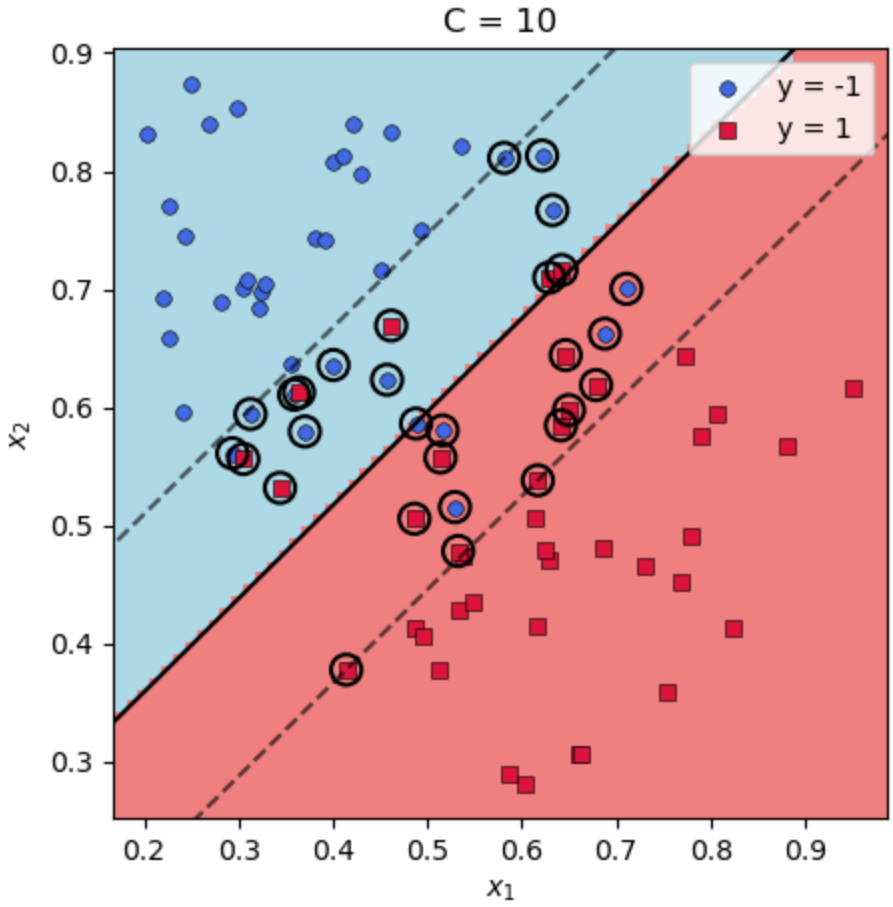
Repeat the above for the linearly non-separable dataset (`X2` and `y2`).

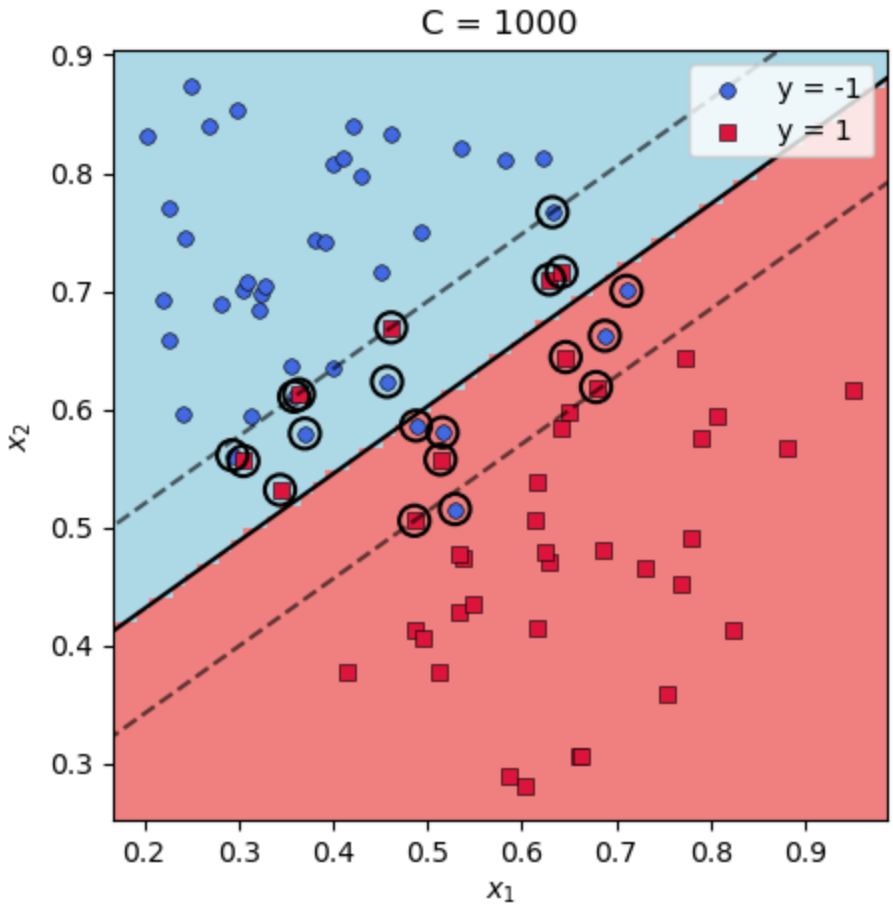
In [13]:
```
C = 5
svm = SVC(C=C,kernel="linear")
svm.fit(X2,y2)
make_plot(f"C = {C}",svm,X2,y2)

for C in [0.1,1,10,1000]:

    model = SVC(C=C,kernel = "linear")
    model.fit(X2,y2)
    make_plot(f"C = {C}",model,X2,y2)
```


C = 5
y = -1
y = 1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
x_2
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
x_1


C = 0.1
y = -1
y = 1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
x_2
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
x_1


C = 1
y = -1
y = 1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
x_2
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
x_1


C = 10
y = -1
y = 1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
x_2
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
x_1



In [ ]: